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EFFECT OF MANUAL LABOR ON PHOSPHORIC ACID ELIMINATION

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ABSTRACT

The authors investigated the effect of strenuous muscular activity on the human metabolic processes. They found that there is a decided loss of phosphoric acid, excreted into the urine and feces, as a direct result of physical labor. Administration of phosphates for some time before the onset of heavy physical work apparently prevents early exhaustion, although the loss of phosphoric acid remains the same. The authors present theoretical explanations of these phenomena.

As indicated in the previous articles by Embden, Grafe and Schmitz /108*
(ref. 1), it is possible to increase muscular work capacity by providing additional sodium phosphate.

Investigations by Embden, Meincke and Schmitz (ref. 2) demonstrated that during muscular labor by rabbits, and under certain experimental conditions by dogs, there is decrease of lactic acid production with splitting off of phosphoric acid in inorganic form in the muscle.

*Numbers given in margin indicate pagination in original foreign text.

It seemed indicated to correlate these two investigations with earlier ones, which had demonstrated at least partly an increase in phosphoric acid excretion under the influence of work.

We would like to mention first the investigation in human subjects by George J. Engelmann (ref. 3), made a long time ago under the direction of /109 Hoppe-Seyler. These tests showed that work, indeed, did lead to increase in the amount of the 24-hour urinary phosphate acid, although not quite regularly.

In contrast to this, Igo Kaup (ref. 4), after self-experiments for three successive years in a deliberately untrained condition, came to the conclusion that muscular labor causes decrease of phosphoric acid excretion, although very irregularly from test to test. Horst Oertel (ref. 5) came to the same conclusion in tests, made at the suggestion of Siegfried, with three different subjects. Oertel's subject E (ref. 5, p. 128, table II) showed a distinct decrease of the excreted inorganic phosphoric acid during the working day, whereas the amount of organic urinary phosphorus remained unchanged. In one of the other two subjects (F.) there was decreased excretion of urinary phosphoric acid during the working day itself, but this was balanced by an almost corresponding increase of excretion on the succeeding day of rest. The test on the third male (G.) did not lead to any clearly recognizable influence on the phosphoric acid excretion, which in this case was quite irregular anyway.

In the investigations which Pettenkofer and Voit (ref. 6) conducted quite some time before those of George Engelmann, there was neither a decisive effect of work on the excretion of phosphoric acid while on a medium diet, nor could such an effect be determined when a nitrogen-free diet was given on the days of rest (the subject fasted during workouts).

A temporary decrease of urinary phosphoric acid excretion, followed /110
by an approximately corresponding increase, was observed by Penzoldt and Fleischer (ref. 7) in a canine bitch under conditions of severe labor.

Dunlop, Paton, Stockman and Maccadam (ref. 8) observed in only two weakly trained subjects an increase of nitrogen and sulfur excretion after excessive muscular work and an increase in phosphoric acid excretion on the following day; this finding was not observed in a third subject who was in excellent training condition.

Although these results mostly disagree with those of Engelmann, another series of authors agree with him as to the increase in phosphoric acid excretion caused by muscular labor. These include the reports by C. Speck (ref. 9), W. North (ref. 19) and A. Mairet (ref. 11). Preysz (ref. 12) also came to this conclusion. He found daily phosphoric acid excretions of 3.00 g (maximum) and 2.56 g (minimum) or an average of 2.78 g in human subjects during a 10-day rest period. On the eleventh days the subjects walked 25 km in 5 hours, with the result that the 24-hour excretion rose to 4.17 g. He confirmed similar behavior on himself and other subjects.

The experiments by Olsavski (ref. 13) agree with this, in this case /111
observed in a small canine bitch which excreted during a 10-day, uniform daily milk diet an approximate average of 0.32 g. On the eleventh day the animal ran 16 km. On this day the phosphoric acid excretion amounted to 0.57 g and returned to the normal rest value on the following day.

As we can see, various investigators obtained widely divergent results in their studies of the effect of work on the excretion of phosphoric acid. Reports of distinct increases of urinary phosphorus oppose those of distinct decreases.

The severe decrease in lactic acid production in the musculature with splitting off of inorganic phosphoric acid during work in animal experiments and the increase in capacity following administration of phosphate in test on human subjects make it imperative to reexamine the effect of muscular activity on the excretion of phosphoric acid.

We began our investigation in 1916 with two young healthy soldiers. We deliberately chose these two subjects (Ma. and Schu.), who showed distinctly increased capacities after administration of phosphate, because we had the possibility in mind that this increased capacity could have been caused by substitution of the phosphoric acid lost during muscular excretion (ref. 14).

Methodology

Of course it was necessary to exclude as much as possible the effect of diet on the excretion of phosphoric acid during these experiments. Therefore we prescribed a diet which was as uniform as it was possible under the conditions of war. The diet was considered satisfactory, calorically /112 speaking, at least for the rest periods; it also contained a sufficient quantity of protein. We considered it of primary importance that the diet contain sufficient amounts of phosphorus, because we wanted to conduct our experiments under conditions of sufficient phosphate intake.

It was our intention to determine exact phosphoric acid balances in our subjects. Unfortunately this was not completely realized, as the following paragraphs show.

Total amount of phosphoric acid was determined in all food stuffs, as well as in the urine and feces.

Table 1 shows the diet and its total amount of phosphoric acid.

TABLE 1.

Daily diet intake		H_3PO_4 in %	H_3PO_4 in g
1. Kommiss bread (sour dough army bread).	400 g	0.602	2.408
2. Potatoes	400 g	0.204	0.816
3. Meat	150 g	0.644	0.966
4. Flour.	30 g	0.275	0.083
5. Beer	600 ccm	0.078	0.468
6. Coffee	1000 ccm	0.0035	0.035
7. Apple sauce.	400 g	0.025	0.100
8. 2 eggs	about 100 g	0.757	0.757
9. Fat[1]	40 g	-	-
10. Table salt	7 g	-	-
11. Sugar.	30 g	-	-
		Daily intake of H_3PO_4	5.633

The food was bought in large quantities at one time and of the most uniform consistency possible in order to avoid fluctuations in its composition. This was not possible in the case of the Kommiss bread, which was found to have quite varying contents of phosphorus with each delivery. /113

In table 1 we assigned a value of phosphoric acid to the bread which we only found in bread delivered later: the content of phosphorus in the bread used as the basis in the table was rather less than that found in later deliveries. It amounted to only 0.437 percent H_3PO_4 instead of 0.602 percent.

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1 An additional 60 g of fat beginning June 26.

This difference is of considerable importance for our investigation, because we unfortunately omitted to analyze each individual loaf of bread.

Because of different deliveries of potatoes, these also had a varying content of phosphorus, but the fluctuations in the amount of dietary phosphorus were considerably smaller than those caused by the differences in the composition of the bread.

Table 1 shows the total content of H_3PO_4 of the daily diet to be 5.63 g.

If as a basis we use the lowest instead of the highest value for meat and potatoes, the daily dietary amount would by only approximately 4.9 g of H_3PO_4.

Another factor complicated the determination of the exact balance of phosphoric acid, namely the fact that we conducted experiments with supplemental intake of phosphoric acid in the form of primary sodium phosphate between the various main periods of the tests, for reasons which cannot be divulged here. Although we started our primary tests only after a number of days of supplemental phosphoric acid, we cannot, perhaps, completely exclude the possiblity that these primary tests showed an expression of the aftereffects of the supplemental phosphate.

Thus, although our experiments as a determination of balance should be evaluated only with great caution, the effect of work, which we had wanted to determine primarily, namely the effect of work on the excretion of phosphoric acid, shows up with some certainty in these tests.

The urinary limiting period was regularly at 7 o'clock in the morning /114 and 7 o'clock in the evening. However, we also examined the urine between the hours in much shorter excretion periods. One hour after emptying the bladder of night urine, that is, at 8 o'clock in the morning, the bladder was emptied again.

It was at this time that during work days the turning of the ergostate wheel occurred, which followed a bell signal ringing every two sec, as in the experiments by Embden, Grafe and Schmitz. The working time varied; usually the soldiers, who were placed in widely separated rooms as in earlier experiments, rotated themselves until they declared that they were unable to work any longer. In the beginning of the tests exhaustion appeared much quicker than in later tests, although with interpolation of long rest periods we no longer obtained such uniform exercise curves as had occurred earlier.

Several times the subject worked a second time after the period of exhaustion had been overcome.

The length of the individual work periods, aside from repeated work periods on the same day, was 158-281 min for Schu. and 182-284 min for Ma. The number of rotations was measured automatically. The subjects were supervised during the entire work period, as previously, and the work was continuous.

Punctually at 10 o'clock and at 12 o'clock 1 to 2 min were spent to empty the bladder. It was also emptied in two-hour intervals, that is, at 2, 4 and 6 in the afternoon and then again at 7 in the evening, which concluded the daytime period.

The same routine for the collection of urine was followed on the rest days. During these rest periods the soldiers were permitted to take moderate walks within the hospital gardens, but any greater exertions were strictly forbidden. The subjects frequently remained in bed all day. /115

The daily dietary intake was divided into the individual meals as much as possible, and the meals were always taken on time.

The individual urinary samples from 7 in the morning to 7 in the evening were measured, and half of their quantity was combined.

This mixture of seven individual samples was used to determine the phosphoric acid. Phosphoric acid determinations were also made for each individual urinary portion. The sum of the individual values always agreed quite well with the results of the analysis of the mixed urine. The phosphoric acid determination was made by titration with a solution of uranyl acetate, of which 1 cc corresponded to 5 mg of H_3PO_4.

In many cases, furthermore, the urine was reduced to ash according to Neumann's method, and the phosphoric acid was determined according to the author's instruction in the liquid ash.

Proceeding on the basis of W. Heubner's report, the computation of the amount of H_3PO_4 was not done with the number of used cc N/2 soda lye, namely 1.75, as required by the original Neumann indications, but it was multiplied by 1.82.

The values obtained by the uranyl method and that of Neumann always were so close (the uranyl values were possibly a little higher), that we could with certainty exclude the presence of any significant amount of organic phosphoric acid not determined by the uranyl method, thus neglecting Neumann's method.

The night urine was prepared in the same manner as the day urine.

In order to determine the phosphoric acid in the feces, the latter /116 was dried in the usual manner on the water bath until it could be pulverized, the dry remainder was weighed, thoroughly mixed and an aliquot portion reduced to ash; the determination of phosphor proceeded according to Neumann.

We used Kjeldahl and Volhard's method to determine nitrogen and chlorine, which we did frequently.

Ma. was placed on this diet on May 17, 1916 and Schu. on May 31. Ma. received 7.5 g of primary sodium phosphate on May 24, 25, 26 and 31 and on June 1.

Beginning with the third of June, the tests were made as uniform as possible for both subjects, that is, during the entire period of uniform diet for both, they worked and rested always on the same days. They were always together outside of the work periods and in the immediately following hours; they also took their walks together in the hospital gardens, so that any straying from the rest period instructions would have had the same effect on both.

Experimental Results

When discussing the experimental results, let us first look at the values of phosphoric acid excretion in the urine of subject Ma., as shown in table 2. The values obtained on the work days are underscored. Column 1 of the table indicates whether the subject rested or worked. The details of the work routine are shown in column 12. When two numbers are given for the same day (numbers of rotation), they indicate a double work period.

Column 2 shows the 24-hour excretion of phosphoric acid in g H_3PO_4.

Column 3 shows the H_3PO_4 excretion from 7 in the morning until 7 at night, column 4 the excretion from 7 at night until 7 in the morning. /117

Columns 5 and 11 indicate the losses of phosphoric acid for the 1-hour periods from 7-8 in the morning and 6-7 in the evening, for better comparison with the succeeding or preceding 2-hour periods, multiplied by 2. Columns 6, 7, 8, 9 and 10 show the values of urinary phosphoric acid found during the periods from 8-10, 10-12, 12-2, 2-4 and 4-6.

The first of the two test periods includes the time from the third to the twenty-first of June, that is, 18 days; the second the time from the ninth to the twenty-fourth of July, or 15 days. On the first day shown in the table, Ma.

TABLE 2. H_3PO_4 - EXCRETION AT REST AND AT WORK.

Date	1	2	3	4	5	6	7	8	9	10	11	12
	Occupation	g H_3PO_4 in 24 hr	From 7 in the morning to 7 in the evening	From 7 PM to 7 AM	From 7-8 x 2	From 8-10	From 10-12	From 12-2	From 2-4	From 4-6	From 6-7 x 2	Rotations
3/4 June	Rest	3.98	2.10	1.88	0.124	0.224	0.276	0.385	0.480	0.396	0.468	
4/5 "	Rest	3.74	1.90	1.84	0.176	0.285	0.252	0.280	0.400	0.364	0.412	
5/6 "	Work	4.20	2.34	1.86	0.156	0.292	0.412	0.388	0.468	0.448	0.484	4632
6/7 "	Work	4.30	2.32	1.98	0.196	0.292	0.388	0.412	0.472	0.432	0.448	5070
7/8 "	Work	4.12	2.30	1.82	0.156	0.252	0.428	0.416	0.492	0.428	0.380	5451
8/9 "	Work	4.18	2.18	2.00	0.168	0.280	0.424	0.368	0.452	0.428	0.388	3200
9/10 "	Rest	3.84	2.04	1.80	0.128	0.240	0.292	0.364	0.428	0.436	0.408	
10/11 "	Rest	4.02	2.08	1.94	0.284	0.180	0.288	0.348	0.488	0.388	0.488	
11/12 "	Rest, partly bed	3.62	1.96	1.66	-	-	-	-	-	-	-	
12/13 "	Rest	3.84	2.04	1.80	-	-	-	-	-	-	-	
13/14 "	Rest, partly bed	3.84	1.88	1.96	0.132	0.172	0.224	0.308	0.452	0.396	0.508	
14/15 "	Complete bed rest	3.54	1.76	1.78	0.104	0.196	0.196	0.308	0.416	0.424	0.328	
15/16 "	Complete bed rest	3.28	1.62	1.66	0.124	0.200	0.184	0.256	0.352	0.376	0.376	
16/17 "	Intensive work	4.34	2.34	2.00	0.184	0.244	0.360	0.388	0.568	0.468	0.472	5515 + 2222

TABLE 2 (Continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Date	Occupation	g H_3PO_4 in 24 hr	From 7 in the morning to 7 in the evening	From 7 PM to 7 AM	From 7-8 x 2	From 8-10	From 10-12	From 12-2	From 2-4	From 4-6	From 6-7 x 2	Rota-tions
17/18 June	Intensive work	4.64	2.62	2.02	0.292	0.380	0.512	0.392	0.532	0.468	0.396	5893 + 2282
18/19 June	Complete bed rest	4.11	2.16	1.95	0.168	0.255	0.256	0.396	0.460	0.440	0.552	
19/20 "	Complete bed rest	3.56	1.86	1.70	0.188	0.248	0.264	0.244	0.428	0.380	0.400	
20/21 "	Complete bed rest	3.44	1.64	1.80	0.164	0.164	0.216	0.312	0.340	0.352	0.356	
9/10 July	Rest	2.78	1.32	1.46	0.064	0.128	0.184	0.254	0.288	0.296	0.296	
10/11 "	Bed rest	2.58	1.26	1.32	0.088	0.124	0.104	0.232	0.312	0.284	0.284	
11/12 "	Work	4.12	2.18	1.94	0.092	0.208	0.312	0.404	0.500	0.448	0.500	7269
12/13 "	Work	4.58	2.62	1.96	0.172	0.300	0.500	0.460	0.624	0.440	0.404	7491 + 1546
13/14 "	Work	4.34	2.62	1.72	0.144	0.336	0.532	0.472	0.536	0.416	0.448	7501 + 1542
14/15 "	Bed rest	3.82	2.10	1.72	0.172	0.252	0.290	0.392	0.464	0.396	0.384	
15/16 "	Bed rest	3.64	1.90	1.74	0.204	0.272	0.240	0.332	0.376	0.384	0.364	
16/17 "	Rest	4.02	2.14	1.88	-	-	-	-	-	-	-	
17/18 "	Rest	3.24	1.64	1.60	0.104	0.184	0.232	0.304	0.325	0.368	0.376	
18/19 "	Bed rest	3.64	1.88	1.76	0.144	0.215	0.180	0.356	0.432	0.396	0.412	

TABLE 2 (Concluded)

	1	2	3	4	5	6	7	8	9	10	11	12
Date	Occupation	g H_3PO_4 in 24 hr	From 7 in the morning to 7 in the evening	From 7 PM to 7 AM	From 7-8 x 2	From 8-10	From 10-12	From 12-2	From 2-4	From 4-6	From 6-7 x 2	Rotations
19/20 July	Bed rest	3.58	1.82	1.76	0.148	0.232	0.216	0.336	0.416	0.360	0.368	
20/21 "	Bed rest	3.72	1.94	1.78	0.208	0.260	0.224	0.336	0.424	0.344	0.460	
21/22 "	Bed rest	3.64	1.96	1.68	0.232	0.265	0.176	0.304	0.452	0.424	0.424	
22/23 "	Work	4.40	2.36	2.04	0.212	0.296	0.364	0.500	0.400	0.444	0.464	7009
23/24 "	Work	5.04	2.84	2.20	0.264	0.420	0.532	0.460	0.552	0.476	0.328	7352

the third of June, the subject rested and excreted 3.98 g H_3PO_4 from 7 in the morning of June 3 to 7 in the morning of June 4 (column 2); 2.10 g (column 3) during the day from 7 in the morning to 7 in the evening; and 1.88 g (column 4) during the night hours of 7 at night to 7 in the morning on June 4.

Let us look first at the 24-hour excretion of phosphoric acid during rest and that during work.

As we can see from column 2, the phosphoric acid excretion was 3.98 g and 3.74 g during the first two days, which were rest periods. During the first work day (5/6 June) it increased to 4.20 g and on the following three work days was 4.30, 4.12 and 4.18 g; on the following days of rest it fell to 3.84, 4.02, 3.62 and 3.84 g.

During several of these rest days Ma. remained in bed for some time during the day; during two days of complete bed rest the 24-hour amount of urinary phosphoric acid consisted of 3.54 and 3.28 g. Two especially strenuous work days followed, and the H_3PO_4 excretion rose to 4.34 and 4.64 g. Immediately thereafter, at the end of the June period, there were three days of complete bed rest, and the excretion fell to 4.11, 3.56 and 3.44.

We see that the amount of phosphoric acid excreted in 24 hours during /120 the work days is very decidedly larger than on the rest days. The same was true of the 24-hour excretion of phosphoric acid during the rest and working periods in July, except that here the differences were even more marked. The excretion values on the rest days of the 9/10 and 10/11 of July are 2.78 and 2.58 g; they rose on the following three work days to 4.12, 4.58 and 4.34 g, and then distinctly fell again on the following rest days, as is shown in detail in the table. From the 20/21 of July and from the 21/22 of July the excretion at bed rest was 3.72 and 3.64 g, and on the last two test days, which were work days, it rose to 4.40 and 5.04 g.

How is the 24-hour excretion of phosphoric acid divided as far as the night and the day periods are concerned? During rest the day and night values are generally closer to one another than during work, while during most rest days the day excretion is greater than the night excretion. These differences are frequently obliterated, so that the day and night amounts of phosphoric acid are either almost the same, or there is a slight predominance of the night excretion. (See columns 3 and 4 for the 13/14, for the 14/15 and for the 15/16 of July, where the differences in favor of the night hardly lie outside of the error limits, which is certainly the case for the 9/10 of July, whereas the greater excretion during the night of the 10/11 of July is again very little.)

On work days the day excretion in Ma. is always markedly and frequently essentially greater than the night excretion, which is shown in detail in table 2.

The differences of phosphoric acid excretion at rest and at work become even more noticeable when we compare certain short excretion periods with one another.

We mentioned previously that the work always began at 8 in the morn- /121
ing. We now turn our attention to column 7, which indicates the excretion of phosphoric acid into the urine at the time from 10-12 o'clock, that is, during the third and fourth hour this entire time on work days.

On the first two days of rest in the June period the amounts of excreted phosphoric acid are 0.276 and 0.252 g in the period of 10-12 o'clock; they increase in the following four work days to 0.412, 0.388, 0.428 and 0.424 g, only to fall again on the first day of rest to 0.292 g.

Later comparative rest and work tests show in part even more distinctive differences in the so-called 2-hour period, which we have indicated by double lines in the table.

This becomes even more evident than in the table in the following graphic representation of the amount of urinary phosphoric acid excreted by Ma. in the 10-12 o'clock period during rest and work (fig. 1). The phosphoric acid excretion on rest days is designated by the broken lines and on work days by the solid lines.

We can see immediately that phosphoric acid secretion during work days is four times that of rest days.

In the 10-12 o'clock period the greater excretion of phosphoric acid during work as compared to rest periods is, indeed, the clearest; it is, however, as table 2 shows, already clearly evident in the 8-10 o'clock period, if we neglect the first four-day work period.

Even in the time period of 12-2 o'clock, during which on work days usually no more work was done and the noon meal had been eaten, there was on work days a decidedly greater excretion; this is also still true for the periods of 2-4 and 4-6 o'clock, although no longer as regularly. The effect of work is even more obliterated in the period of 6-7 o'clock, where the doubled excretion values are indicated in column 11.

Finally we would like to point out that excretion of phosphoric acid /123 apparently already depends on the fact whether the subject lies quietly in bed or moves outside of bed. The 24-hour amount of excretion does not make this clear. However, we should like to turn our attention to the fact that on the seven days of rest without complete bed rest, during which the determinations were made every 2 hours, the phosphoric acid excretion (with one exception of the 4/5 of June) was always less in the period of 8-10 o'clock than in the period of 10-12 o'clock, whereas on the 12 days of complete bed rest the characteristic behavior for the rest days without bed rest occurred only three

Schu.

TABLE 3. H_3PO_4 - EXCRETION AT REST AND AT WORK.

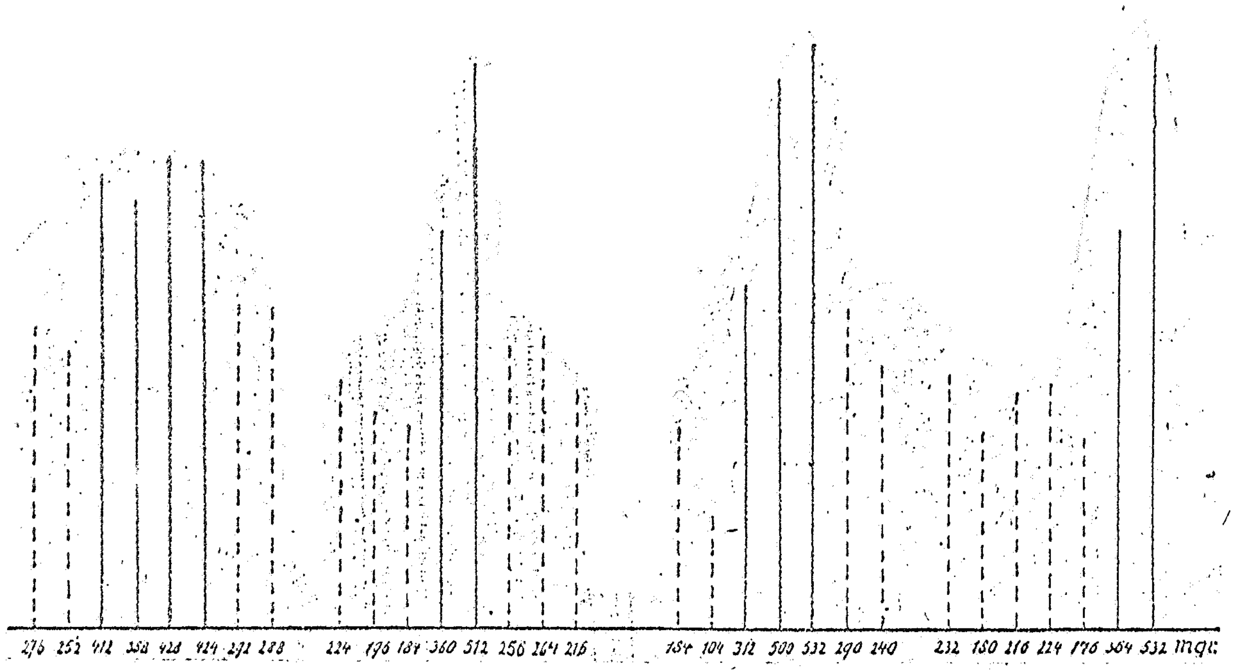
	1	2	3	4	5	6	7	8	9	10	11	12
Date	Occupation	g H_3PO_4 in 24 hr	From 7 in the morning to 7 in the evening	From 7 PM to 7 AM	From 7-8 x 2	From 8-10	From 10-12	From 12-2	From 2-4	From 4-6	From 6-7 x 2	Rota-tions
3/4 June	Rest	4.32	2.14	2.18	0.124	0.196	0.292	0.388	0.468	0.490	0.432	
4/5 "	Rest	4.24	2.10	2.14	0.272	0.332	0.264	0.348	0.448	0.352	0.412	
5/6 "	Work	4.44	2.06	2.38	0.244	0.240	0.324	0.272	0.336	0.516	0.488	4715
6/7 "	Work	4.34	2.10	2.24	0.192	0.324	0.344	0.328	0.396	0.344	0.512	4908
7/8 "	Work	4.16	2.08	2.08	0.256	0.204	0.480	0.316	0.356	0.436	0.372	5326
8/9 "	Work	4.18	2.18	2.00	0.324	0.332	0.428	0.224	0.396	0.404	0.404	5647
9/10 "	Rest	4.52	2.40	2.12	0.260	0.296	0.340	0.416	0.460	0.480	0.416	
10/11 "	Rest	4.38	2.28	2.10	0.448	0.216	0.336	0.384	0.468	0.420	0.420	
11/12 "	Rest	3.96	1.80	2.16	-	-	-	-	-	-	-	
12/13 "	Rest	4.52	2.24	2.28	-	-	-	-	-	-	-	
13/14 "	Rest	4.22	1.74	2.48	0.248	0.252	0.188	0.192	0.268	0.412	0.448	
14/15 "	Bed rest	3.58	1.70	1.88	0.384	0.268	0.155	0.256	0.384	0.344	0.200	
15/16 "	Bed rest	3.98	1.96	2.02	0.196	0.328	0.220	0.292	0.384	0.416	0.364	
16/17 "	Intensive work	4.82	2.30	2.52	0.328	0.304	0.360	0.328	0.460	0.524	0.328	5748 + 2297
17/18 "	Intensive work	4.84	2.40	2.44	0.328	0.388	0.492	0.348	0.336	0.436	0.436	5913 + 2559

TABLE 3 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12
Date	Occupation	g H_3PO_4 in 24 hr	From 7 in the morning to 7 in the evening	From 7 PM to 7 AM	From 7-8 x 2	From 8-10	From 10-12	From 12-2	From 2-4	From 4-6	From 6-7 x 2	Rotations
18/19 June	Bed rest	4.30	2.20	2.10	0.284	0.336	0.216	0.392	0.460	0.432	0.412	
19/20 "	Bed rest	4.26	2.28	1.98	0.336	0.332	0.368	0.308	0.444	0.472	0.400	
20/21 "	Bed rest	4.36	2.14	2.22	0.408	0.256	0.244	0.360	0.404	0.482	0.372	
9/10 July	Rest	2.98	1.42	1.56	0.192	0.160	0.192	0.288	0.284	0.284	0.228	
10/11 "	Bed rest	3.78	1.82	1.96	0.288	0.268	0.165	0.216	0.476	0.388	0.288	
11/12 "	Work	4.46	2.14	2.32	0.308	0.300	0.320	0.368	0.388	0.388	0.476	6755 + 2330
12/13 "	Work	4.74	2.42	2.32	0.304	0.352	0.444	0.440	0.416	0.380	0.468	6956 + 2162
13/14 "	Work	4.48	2.34	2.14	0.292	0.388	0.344	0.492	0.344	0.368	0.508	7103 + 2252
14/15 "	Bed rest	4.26	2.42	1.84	0.336	0.364	0.325	0.456	0.476	0.510	0.368	
15/16 "	Bed rest	4.00	2.16	1.84	0.308	0.344	0.292	0.420	0.384	0.404	0.396	
16/17 "	Rest	4.28	2.18	2.10	-	-	-	-	-	-	-	
17/18 "	Rest	3.90	2.06	1.84	0.292	0.310	0.320	0.348	0.388	0.375	0.356	
18/19 "	Bed rest	4.04	2.06	1.98	0.332	0.304	0.216	0.340	0.408	0.424	0.396	
19/20 "	Bed rest	3.72	1.84	1.88	0.260	0.296	0.188	0.340	0.460	0.356	0.144	

TABLE 3 (Concluded)

	1	2	3	4	5	6	7	8	9	10	11	12
Date	Occupation	g H_3PO_4 in 24 hr	From 7 in the morning to 7 in the evening	From 7 PM to 7 AM	From 7-8 x 2	From 8-10	From 10-12	From 12-2	From 2-4	From 4-6	From 6-7 x 2	Rotations
20/21 July	Bed rest	3.76	1.92	1.84	0.244	0.360	0.196	0.324	0.356	0.388	0.344	
21/22 "	Bed rest	4.28	2.18	2.10	0.372	0.356	0.192	0.292	0.440	0.480	0.436	
22/23 "	Work	4.78	2.34	2.44	0.284	0.068	0.652	0.412	0.388	0.450	0.428	7543
23/24 "	Work	4.48	2.20	2.28	0.336	0.360	0.432	0.388	0.348	0.308	0.344	7549



Ma.

Figure 1. H_3PO_4-Excretion at rest and work.

times (on the 19/20 and 20/21 of June and on the 14/15 of July). On the nine other days of complete bed rest, however, only as much phosphoric acid or less is excreted in the period of 10-12 than in the last-named period.

We will now discuss the excretion of phosphoric acid in subject Schu., and once more call attention to the facts that the diet was exactly the same for both subjects during the entire experimental time, and that both always rested and worked on the same days. Their different muscular capacities naturally caused some difference in the magnitude of their work performances.

We shall look first here too at the 24-hour excretion of phosphoric acid (table 3). We observe that it is no higher during the first period of work on June 5-9 in Schu., partly even lower than on the preceding and following days of rest. [illegible] the later test periods, however, the phosphoric acid secretion is distinctly increased on work days in this subject also.

We saw that in Ma. the day excretion of phosphoric acid was higher in most cases than the night excretion. The conditions were different with Schu., in whom the night excretion was higher than the day excretion on half of the rest days (11 of 22); here it is noticeable that during the later course of the /126 tests this amount approached that of Ma.

As we have mentioned, the day excretion in Ma. is always decidedly larger than the night excretion during the work period: this is different with Schu. He excreted more phosphoric acid on 7 of 11 work days during the night following work than he did during the day hours (on the 7/8 of June day and night excretions were the same), and the day excretion outweighed the night excretion only three times, on the 8/9 of June and on the 12/13 and 13/14 of July.

Apparently the increase in phosphoric acid excretion due to work performance is of longer duration in Schu. than in Ma., which is also evident from the 24-hour amounts of phosphoric acid on the first day after work. (See column 2 of tables 2 and 3.)

The appearance of an increase in excretion due to work also occurs very rapidly in Schu., because in this case we also observe that the urinary phosphoric acid is tremendously increased in the period of 10-12 o'clock during the work days, as compared to the rest days. The graphic reproduction in figure 2 shows the excretions at rest and at work during this period in detail.

The phosphoric acid excretion is not nearly as varied during the noon and afternoon hours as was the case with Ma.

We can thus conclude that in many respects the effect of rest and work on phosphoric acid excretion was not nearly as characteristic in Schu. as it was in Ma. Perhaps this is associated with the livelier temperament of Schu., who was a rather intelligent and versatile big-city man, whereas Ma. came from the country and was much quieter, although in no way unintelligent. There was probably more muscular activity in Schu. during the rest periods than in Ma.

This may also be the reason that the difference in the course of phos- /127 phoric acid excretion during ordinary rest and during bed rest was more evident in Schu. than in Ma.

On the seven rest days without bed rest the phosphoric acid excretion is greater only twice (on the fourth and thirteenth of June) in the period of 8-10 than in the period of 10-12, whereas in the other five days the amount of urinary phosphoric acid secretion is far greater in the period of 10-12 than in the preceding 2-hour period. In contrast Schu. excreted eleven times more in the two hours from 8-10 than in the following period during the 12 days of complete bed rest. Only once, on June 19, was there a definite difference in favor of the latter.

There can be no doubt of the fact that even getting out of bed has an effect on the excretion of phosphoric acid. The most probable interpretation of this observation seems to us to be that the increase in muscular activity associated with giving up bed rest causes the increased excretion. However, we wish to emphasize that both subjects partook of a breakfast at 7 in the morning, consisting of coffee, 250 g Kommiss bread and lard. It is conceivable, even though we consider it improbable, that bed rest retarded the digestion and resorption of breakfast to some extent, and that thus the excretion of phosphoric acid derived from the bread was slowed up.

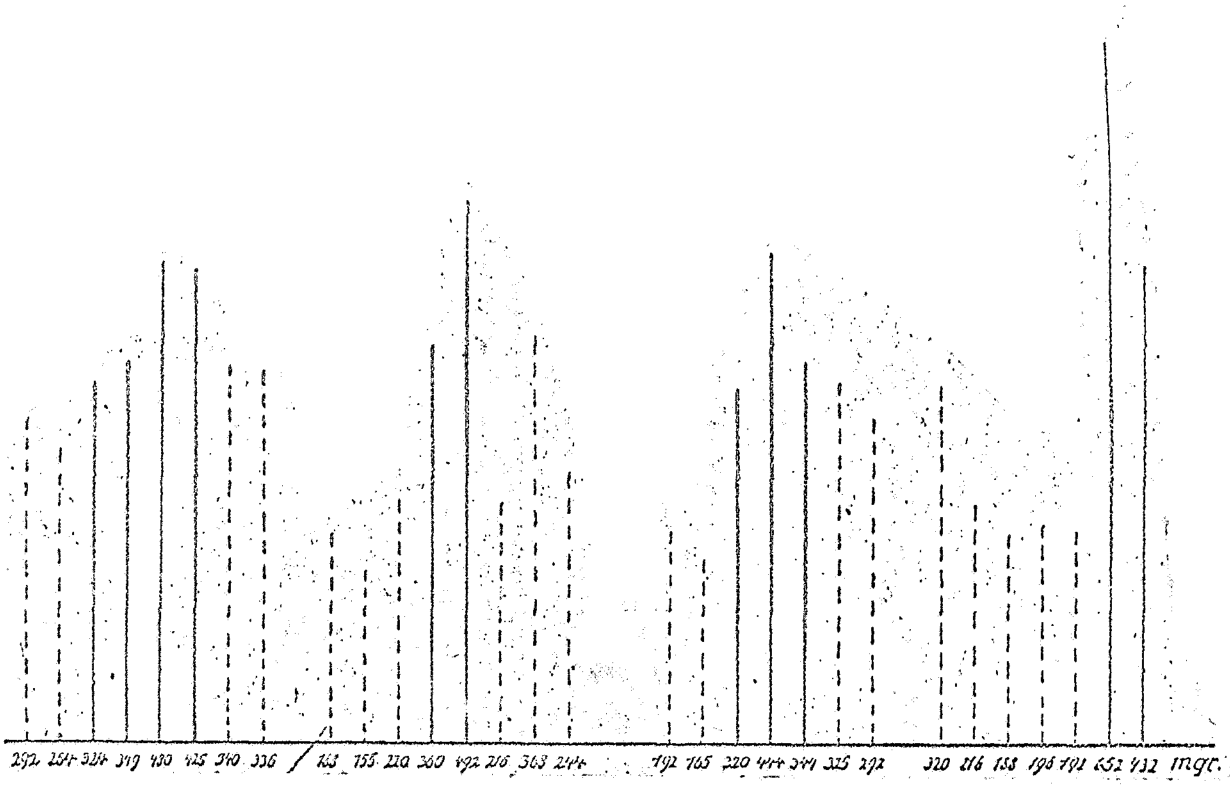
So far we have been occupied exclusively with the excretion of phosphoric acid in the urine. We will now turn to a discussion of the P losses in the feces. Unfortunately the fecal limits were not sharply fixed, and furthermore the fecal amounts of any two days were mixed, a procedure in which unfortunately in most cases the feces from a rest day and a work day were combined.

It is thus quite impossible to obtain an accurate picture of the loss of /129 phosphoric acid through the intestine from the individual rest and work days.

Table 4 indicates in column 2 Ma's urinary excretion of phosphoric acid occurring on two successive test days; column 3 indicates the P loss by way of the feces in approximately the same time. The total excretion in urine and feces is given in column 4.

Because of the inaccuracy of the individual value of fecal excretion we /130 shall not discuss this further, except to emphasize that during the first 18-day test period about 70.6 g H_3PO_4 was excreted in the urine and 31.1 g in the feces, a total of about 101.7 g.

At the same time Schu. excreted 77.4 g in the urine and 23.6 g H_3PO_4 in the feces, or a total of 101.0 g (table 5), agreeing surprisingly well with the total excretion observed in Ma.



Schu. Figure 2. H_3PO_4-Excretion at rest and at work.

Ma.

TABLE 4. PHOSPHORIC ACID BALANCE.

1	2	3	4	5
Date	Excretion			Intake
	in urine	in feces	total	
June 3/4	7.72	4.54	12.26	
" 5/6	8.50	2.53	11.03	
" 7/8	8.30	3.73	12.03	
" 9/10	7.86	4.17	12.03	
" 11/12	7.46	3.68	11.14	
" 13/14	7.38	0.42	7.80	
" 15/16	7.62	5.27	12.89	
" 17/18	8.75	2.14	10.89	
" 19/20	7.00	4.62	11.62	
	70.59	31.10	101.69	
Daily average	3.92	1.73	5.65	5.63?
July 9/10	5.36	2.60	7.96	
" 11/12	8.70	4.60	13.30	
" 13/14	8.16	2.45	10.61	
" 15/16	7.66	3.60	11.26	
" 17/18	6.88	1.98	8.86	
" 19/20	7.30	3.86	11.16	
" 21/22	8.04	3.70	11.74	
" 23/24	8.92	2.24	11.16	
	61.02	25.03	86.05	
Daily average	3.81	1.56	5.38	5.63?

Schu.

TABLE 5. PHOSPHORIC ACID BALANCE

1	2	3	4	5
Date	Excretion			Intake
	in urine	in feces	total	
June 3/4	8.56	1.37	9.93	
" 5/6	8.78	1.33	10.11	
" 7/8	8.34	2.81	11.15	
" 9/10	8.90	4.30	13.20	
" 11/12	8.48	2.38	10.86	
" 13/14	7.80	2.99	10.79	
" 15/16	8.80	2.94	11.74	
" 17/18	9.16	2.80	11.96	
" 19/20	8.62	2.68	11.30	
	77.44	23.60	101.04	
Daily average	4.30	1.31	5.61	5.63?
July 9/10	6.76	1.97	8.73	
" 11/12	9.20	2.98	12.18	
" 13/14	8.74	3.14	11.88	
" 15/16	8.28	2.90	11.18	
" 17/18	7.94	1.85	9.79	
" 19/20	7.48	2.97	10.45	
" 21/22	9.02	2.69	11.71	
" 23/24	8.74	2.10	10.84	
	66.16	20.60	86.76	
Daily average	4.14	1.29	5.43	5.63?

The conditions are quite similar in the second test period, in which /131 we also considered the urinary excretion of the 24/25 of July (not indicated in tables 2 and 3), in order to obtain corresponding urinary and fecal periods.

In this 16-day period Ma. excreted 61.02 g in the urine and 25.03 g in the feces, or a total of 86.0 g of phosphoric acid, while Schu. excreted 66.2 g in the urine and 20.6 g in the feces, or a total of 86.8 g.

Thus we obtained in both periods very closely similar phosphoric acid excretion, although Ma. excreted relatively less urinary H_3PO_4 and more fecal H_3PO_4 than Schu. Of the total amount of excreted phosphoric acid, Ma. excreted 69.4 percent in the urine and 30.6 percent in the feces during the June period, and in the July period, closely corresponding, 70.8 percent in the urine and 29.2 percent in the feces. Schu. however, lost 76.4 percent in the urine and 23.3 percent in the feces during the June period, which corresponds excellently to the July period (76.2 percent in the urine and 23.8 percent in the feces).

We cannot, of course, determine from our experiments whether Schu. resorbed more phosphoric acid, especially from the bread which contained bran (ref. 15), or whether he excreted less phosphoric acid through the intestinal wall.

As we already stated, it is not possible to draw reliable phosphoric acid balances because of the gaps in the determination of dietary phosphoric acid.

Nevertheless we wish to compare, based on the values laid down in table 1 for the intake of phosphoric acid, the average daily consumed and excreted amounts of phosphoric acid during the June and July periods. Compared to a continuous (?) (see p. 113) H_3PO_4 intake of 5.63 g, Ma. excreted an average daily 5.65 g during the 18-day June period and 5.38 g in the 16-day July /132 period, while Schu. excreted 5.61 g in the June period and 5.43 g in the July period.

Thus both subjects were apparently not far removed from a phosphorus balance, and the losses of phosphorus appearing during and after work were later equalized. However, we cannot maintain this with any confidence in view of the uncertainty attached to the amount of phosphoric acid intake and the fluctuation under which the intake suffered because of the changeable composition of the Kommiss bread.

The most essential result of our experiments is that with a uniform diet muscular activity can produce a considerable and, when considering the 2-hour experimental periods, even a tremendous increase in the excretion of phosphoric acid.

We shall now discuss the implications of the increased phosphoric acid excretion during work.

We might at first believe that the increased loss of phosphoric acid in the urine is caused by increased secretory activity of the kidney under working conditions, since we know that there can be increased diuresis at certain times during muscular activity.

In order to prove this question, we also determined the nitrogen and chlorine excretion, sometimes in the same short intervals as the phosphoric acid excretion. We found that neither increased nitrogen excretion nor increased chlorine loss corresponds to increased phosphoric acid excretion.

We shall not discuss these experiments in detail, but wish to emphasize that in the 2-hour periods, for example, those from 10-12 o'clock, during which at work the increase of phosphoric acid excretion was especially evident, there was no characteristic change in the nitrogen excretion. /133

Chlorine excretion was somewhat different. We found that there is not only no parallelism between phosphoric acid and chlorine excretions during work, but that on the contrary there exists an outspoken antagonism. The decrease in the 24-hour chlorine excretion was evident on those work days during which, as we have seen, the phosphoric acid excretion was increased.[1]

It is probable that the decrease in chlorine excretion in the urine after strenuous work is due to increased sweat secretion.

However, aside from the fact that this was not particularly evident, in other words, was probably not very intense, the often considerable increase above normal of chlorine excretion on the first rest day following work, during which P excretion fell, speaks against this; these observations were made on both subjects and were in agreement.

For reasons we will not discuss here we occasionally administered considerable amounts of phosphate to both subjects at bed rest. We observed that increased phosphoric acid intake had the effect of diminishing chlorine excretion for that day. Thus it appears that not some other effects connected with increased phosphorus excretion cause the decrease in chlorine excretion, but that the cause for the decrease is specifically the increase in phosphoric acid excretion or an existing increase in the content of phosphoric acid in the blood.[2]

We forego, therefore, any further discussion of this problem, before new /134 investigations are made and also omit an exact report of our tests on chlorine excretion.

In this report it was our primary purpose to show that increase of phosphoric acid excretion during work is not an expression of increased total diuresis, but a specific reaction.

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[1] The chlorine determinations were conducted by Dr. Prigge.

[2] Feigl recently observed increase of the content of phosphoric acid in the blood serum after work.

However, even with this knowledge we are still not very close to a complete explanation of this phenomenon.

Nearest at hand is undoubtedly the explanation that the increase in excretion of phosphoric acid through the kidneys is an expression of increase of phosphoric acid output on part of the muscles to the blood. We do know with certainty that during work there is increased splitting off of lactic acid in the mammalian muscle and liberation of inorganic phosphoric acid, which was shown by the work of Embden, Schmitz and Meincke, as we mentioned previously, and that of F. Cohn (ref. 16). In the case of the frog, whose muscles did not show any recognizable increase in inorganic phosphoric acid on simple stimulation, although there was sufficient lactic acid production, the excretion of phosphoric acid from the muscles during contraction was demonstrated from quite a different viewpoint than that taken in the reports just mentioned (ref. 17).

It is thus quite probable that during work more excreted phosphoric acid originates in the active muscle directly.

It would not be too misleading briefly to discuss another possibility of an explanation. It is conceivable that during strenuous muscular activity not only one component of lactic acid, namely sugar, as we know with cer- /135 tainty, is conveyed in increased quantities to the muscles, but that the muscle may also receive the other component of the contraction substance, phosphoric acid, from some other storage places in increased quantities. The increased phosphoric acid in the blood thus created would naturally lead to increased phosphoric acid excretion in the urine.

If this explanation were true, the organism would proceed in the same manner for prolonged muscular activity as in the experiments in which we obtained increased muscular performance by supplemental phosphate. Thus administration of phosphate in order to increase performance would be closely related and well adapted to the normal physiologic processes.

However, this may be (we do not consider it impossible that the increase in loss of phosphate during work may come about by both methods), the fact of increased phosphoric acid losses during muscular activity urgently indicated the necessity of sufficient supplemental phosphoric acid especially during work, and for the composition of the diet for especially hard working men we must pay more attention to the content of metabolic phosphoric acid than we have done heretofore (ref. 18).

It is not very clear why such a pronounced increase of phosphoric acid excretion took place during work in our two subjects, to a degree that has hardly been observed previously and which is in contrast to the previously mentioned self-experiments of Kaup, who observed decrease of phosphoric acid excretion after strenuous work.

Perhaps the result of our experiment depended to some extent on the fact that our subjects Ma. and Schu. both responded to increased administra- /136
tion of phosphate with particularly emphatic increase in capacity. We must also remember that Kaup made his experiments deliberately in a completely untrained condition, whereas Ma. and Schu., when we conducted our metabolic tests on them, already had behind them a longer, occasionally interrupted training period.

Keeping in mind this briefly developed theoretical explanation, the muscle would be capable of taking up increased quantities of sugar from the blood just as it can absorb increased quantities of phosphoric acid under work conditions (ref. 19). This would agree with the finding by Macleod (ref. 20), conducted under the direction of Siegfried, that the total amount of phosphoric acid in the canine muscle is considerably increased during muscular activity.

We intend to investigate in what manner phosphoric acid secretion changes with increased training. Our present investigations--especially in correlation with those by Kaup--do not seem to indicate that increased training will cause a decrease in phosphoric acid loss, but rather point in the opposite direction.

The most essential result of our work consisted in the fact that in two young men, in whom previous supplemental phosphate had produced increased muscular capacity, work capacity while on a uniform diet was connected with greatly increased urinary phosphoric acid excretion.

This increase in phosphate excretion is especially noticeable if the /137 urine is examined in periods of a few hours. It is most distinctly expressed in the period of 10-12 o'clock during a regime of work beginning at 8 in the morning, thus after 3-5 hours of exhausting regular ergostatic labor or the later period of work. The effect of work may be prolonged and may cause considerable increase in the 24-hour quantity of phosphoric acid in the urine.

The results are far from presenting a sufficient explanation for the capacity-increasing effect of supplemental phosphate, but they urgently indicate the importance of a sufficient quantity of phosphoric acid in the diet for physical labor.

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